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Panoramic Night Vision Goggle Flight Test Results

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ABSTRACT

The Panoramic Night Vision Goggle (PNVG) has begun operational test and evaluation with its 100-degree horizontal by 40-degree vertical field of view (FOV) on different aircraft and at different locations. Two configurations of the PNVG are being evaluated. The first configuration design (PNVG I) is very low in profile and fits underneath a visor. PNVG I can be retained by the pilot during ejection. This configuration is interchangeable with a day helmet mounted tracker and display through a standard universal connector. The second configuration (PNVG II) resembles the currently fielded 40-degree circular FOV Aviator Night Vision Imaging System (ANVIS) and is designed for non-ejection seat aircraft and ground applications. Pilots completed subjective questionnaires after each flight to compare the capability of the 100-degree horizontal by 40-degree vertical PNVG to the 40-degree circular ANVIS across different operational tasks. This paper discusses current findings and pilot feedback from the flight trials. Objectives of the next phase of the PNVG program are also discussed.

Keywords: Night Vision Goggles, Panoramic Night Vision Goggles, Helmet-Mounted Display, Wide Field of View, Flight Test, Night Operations, and Image Intensifiers Tubes

1. INTRODUCTION

The Panoramic Night Vision Goggle (PNVG) (Figures 1 and 2) provides pilots a larger viewing area than current night vision goggles. Unlike previous attempts to increase field of view (FOV), comfort, safety, and resolution have not been sacrificed.



Figure 1: PNVG I in a F-15E



Figure 2: PNVG II in a C-5

The PNVG approach uses four image intensifier (I^2) tubes that are each 60% smaller and lighter than conventional I^2 tubes. The Aviator Night Vision Imaging System (ANVIS) uses two standard I^2 tubes. The key to getting the I^2 tubes smaller and lighter was the design of a 16-mm format versus the standard 18-mm format (Figure 3). The use of four I^2 tubes provides the PNVG capability of a 100 horizontal degree by 40 degrees vertical FOV. The result is an increase of the viewing area by 160% versus current night vision goggles (NVGs) (Figures 4 and 5). Resolution is not compromised because the number of

pixels per unit area is not decreased. For PNVG, the center 30 degrees horizontal by 40 degrees vertical is binocular with the right 35 degrees visible only to the right eye and the left 35 degrees visible only to the left eye. The PNVG has two different design configurations: PNVG I and PNVG II.

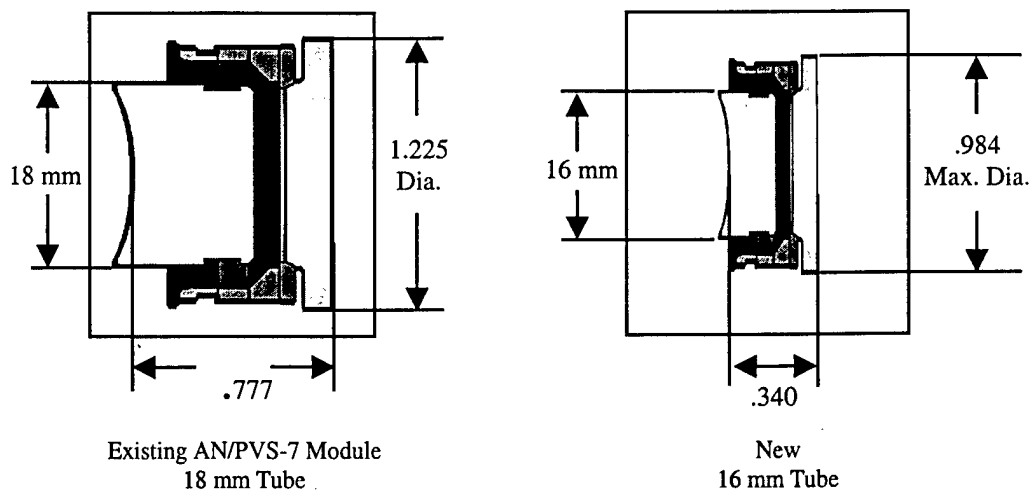


Figure 3

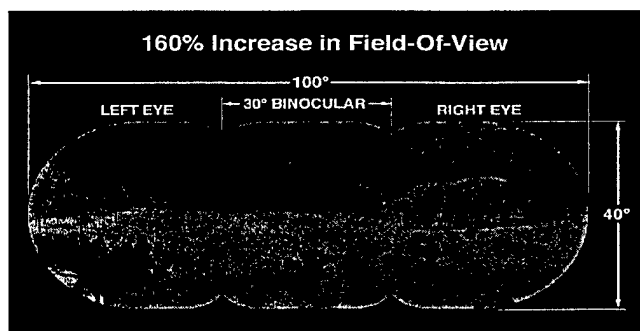


Figure 4: Simulated PNVG FOV

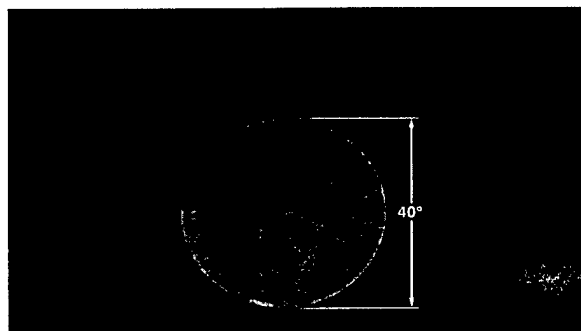


Figure 5: Simulated 40° NVG FOV

1.1 PNVG I

PNVG I (Figure 1) is a low-profile version that is designed to be used in ejection seat aircraft. The system is designed to be retained throughout the ejection sequence and to be used for escape and evasion versus the current NVGs that need to be removed before ejection because of the risk of injury. The PNVG I had lower windblast loads than the standard HGU-55/P.¹ Figure 6 depicts the low-profile nature of PNVG I versus the standard NVGs. The center of gravity of the PNVG I is closer to the center of gravity of head to make it more comfortable and less fatiguing. The PNVG I is interchangeable with the Visually Coupled Acquisition and Targeting System (VCATS) module that is used for day missions. Both the PNVG and VCATS interface through the use of Air Force Research Laboratory's (AFRL) Universal Connector (Figure 7) mounted on a lightweight HGU-55/P helmet.² The system can be powered via either aircraft power through AFRL's standardized helmet vehicle interface or the system can be powered using two "AAA" alkaline batteries. The PNVG I has demonstrated the capability to perform off-boresight cueing using the head tracker with the symbology overlay.

1.2 PNVG II

The PNVG II (Figure 2) is similar in design to the ANVIS goggles. The PNVG II is more rugged than PNVG I and will probably be cheaper to produce. The PNVG II was designed for the transport, helicopter, and ground force community who do not require the ejection safe goggles. The goggles will attach to any helmet that has an ANVIS mounting bracket. The system is powered by using one "AA" lithium battery.

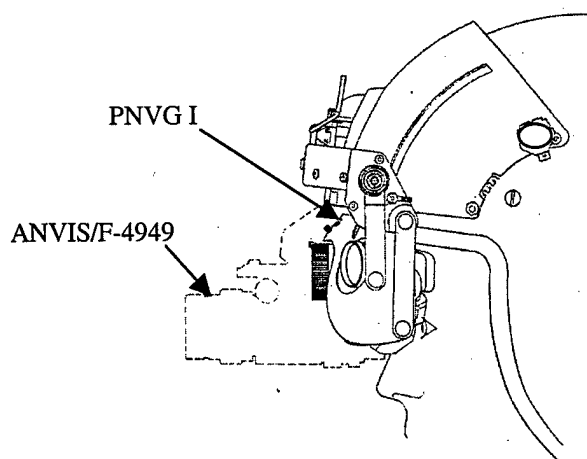


Figure 6: PNVG I Versus ANVIS Profile

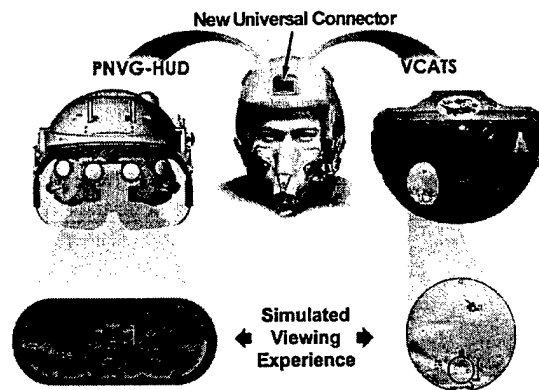


Figure 7: Universal Connector

2.0 EVALUATION METHOD

Several operational utility evaluation (OUE) efforts have been initiated to evaluate PNVG I and PNVG II. Laboratory experiments are also being performed to address specific questions regarding performance and SA effects attributable to the PNVG FOV. The objective of the OUE is to expose the PNVG to the operational environment to investigate the impact the technology has on mission effectiveness and survivability. The OUE process includes the development of new tactics which result from the application of new technology. The data presented here were produced via questionnaires completed by operational test pilots who flew with the PNVG I and PNVG II during evaluation flights. The PNVG I data were collected at the 422nd Test and Evaluation Squadron at Nellis AFB, Nevada. Data are included from 16 different F-15E flights and 10 F-15C flights. At the date of this writing, a total of 12 pilots participated in the PNVG I evaluation flights. Four of the 12 pilots each flew two different sorties. Three of the four duplication flights were in F-15C's. Both air-to-air and air-to-ground missions were completed. Crews from 50th and 61st Airlift Squadrons flew with PNVG II during evaluation flights at Little Rock AFB, Arkansas. A total of nine crewmembers flew with PNVGII aboard the C-130 aircraft. The evaluators included six pilots and three navigators. The majority of these missions were multi-ship formation flights. Twelve crewmembers from the 3rd and 9th Airlift Squadron and 436th Air Wing at Dover AFB, Delaware evaluated PNVG II during C-5 missions. The C-5 flights were mostly single ship low-level airdrop missions. The C-5 evaluators included six pilots, four navigators, one flight engineer, and one loadmaster. All of the C-130 and C-5 crewmembers reported significant experience with conventional F-4949 NVGs. A post-flight questionnaire was developed to collect evaluators' impression of PNVG I and II across different areas of interest during each evaluation flight.

2.1 Questionnaire and rating scale

A rating scale was developed to compare pilots' experience with PNVGs versus their previous experience with F-4949s. It was not feasible to directly compare the PNVG (I and II) to F-4949 on a flight by flight basis. Instead, the questionnaire instructions asked pilots to compare their recent experience with PNVG I or II vs. their past experience with F-4949s. All of the participants had significant flight experience with the conventional F-4949 NVGs. A rating methodology was developed to allow the evaluators to quantify their comparison of the NVGs. Table 1 shows the rating scale developed for the questionnaire. Questions were formed for the following categories: 1) Fit, Function, and Human Factors, 2) Cockpit/Cockpit Lighting Compatibility, 3) Image Quality, and 4) Operational Employment. Where possible, comparison ratings were collected. Where appropriate, yes/no format questions were asked. Comments were solicited at the end of each category section of the questionnaire. A final section of the questionnaire was dedicated to additional comments designed to collect information about the advantages and disadvantages of the PNVG.

RATING SCALE		RESPONSE
1	Very Ineffective	PNVG performance is significantly less than that of the F-4949 and significantly affects safety of flight or detracts from successful task/mission accomplishment.
2	Ineffective	PNVG does not perform as well as the F-4949 and detracts from task/mission accomplishment.
3	Same	PNVG and F-4949 performance does not differ.
4	Effective	PNVG performs better than the F-4949 and enhances task/mission accomplishment.
5	Very Effective	PNVG performance is significantly better than the F-4949 and significantly enhances safety of flight or adds to successful task/mission accomplishment.

Table 1. PNVG questionnaire rating scale.

3.0 RESULTS

3.1 F-15 PNVG I evaluation

The following paragraphs present the questionnaire data collected to date. The information represents averages derived across all 16 sorties. It is indicated where feedback is specific to an aircraft type (F-15C or F-15E). A statistical analyses (two-tailed t tests) were performed to determine if the recorded ratings differed reliably from a rating of 3 (a rating of 3 would indicate that PNVG I and F-4949 performance was the same).

3.1.1 Descriptive information

Average takeoff time was 42 minutes after local sunset. Average duration of the flight was 1 hour 32 minutes (1:32). Illumination conditions were described as high for slightly more than half the flights (62.5%). Average moon presence was 68.3% and the observed weather was described as clear for the majority of the flights (91.6%).

3.1.2 Fit, function, and human factors ratings:

Pilots found the PNVG I to be easier to don than the F-4949 (mean rating = 4.25, $p < 0.0001$). For weight and center of gravity, the operating comfort of the PNVG I was rated as better than the F-4949 (mean rating = 3.94, $p < 0.005$). In the stowed position, ratings indicated greater comfort compared to the F-4949 (mean rating = 3.67, $p < 0.05$). Stability of the PNVG I during head movements, G loading, and vibration was rated as slightly better than F-4949 (mean rating = 3.66, $p < 0.05$). In some cases, the helmet was not custom fit to the pilot. Questions concerning PNVG I position and focus adjustability indicate that this is an area of design criticism. Both position and focus were rated as the "same" compared to F-4949. Peripheral vision around the PNVG I and the ability to look under the PNVG I to view cockpit instrumentation was rated as very similar to F-4949. The compatibility of the PNVG I with the use of a clear visor was rated as better than F-4949 compatibility (mean rating = 3.75, $p < 0.05$). For pilot comments, please refer to Geiselman and Craig (1999).³

3.1.3 Cockpit/cockpit lighting compatibility

Cockpit clearance of the PNVG I was rated during scanning behavior. In the operational position, clearance was rated better with PNVG I than with F-4949 (mean rating = 3.81, $p = 0.01$). In stowed position, clearance was similar that of the F-4949 (mean rating = 3.31, $p = 0.13$). Cockpit display compatibility for PNVG I was rated as similar to F-4949. This was true also for HUD and NVIS lighting compatibility. PNVG I was rated as more compatible with "Christmas tree" lighting (mean rating = 4.14, $p = 0.01$) than the F-4949.

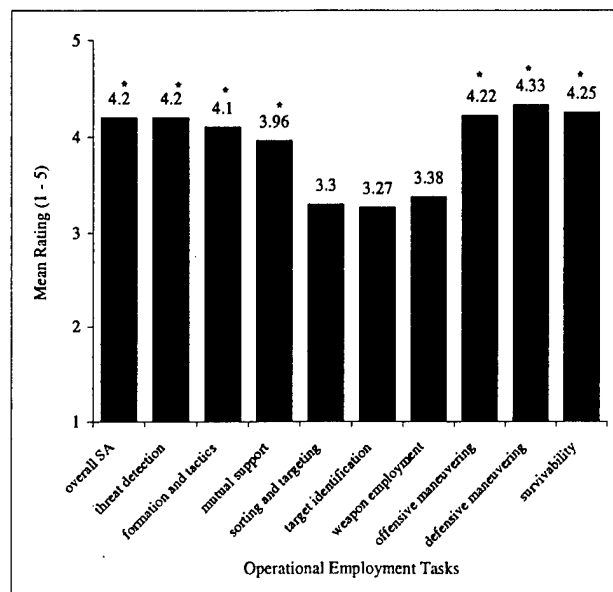


Figure 8. PNVG I ratings as a function of operational employment task

3.1.4 Image Quality

Overall PNVG I image quality was rated as similar to F-4949 (mean rating = 3.47, $p = 0.13$). Similar findings were recorded for a question addressing the ability to distinguish cultural (mean rating = 3.5, $p < 0.05$) and terrain features (mean rating = 3.5, $p = 0.1$). PNVG I image brightness acceptability was rated higher than F-4949 (mean rating = 3.59, $p = 0.007$). Image brightness consistency across the tubes was indicated during 69% of the sorties. The acceptability of image noise for PNVG I was rated to be similar to F-4949.

3.1.5 Operational employment

Pilots reported that 5.5 G's could be sustained comfortably while using the PNVG I. The maximum reported G load across these test flights was 8.0. Pilots were asked if the PNVG I ever inadvertently came down from the stowed position during the flight. This occurred during 2 of the 16 flights (12.5%). The pilots reported that overall, SA was enhanced by the use of PNVG I compared to F-4949 (mean rating = 4.2, $p < 0.0001$). Figure 8 shows the pilots' mean ratings comparing PNVG I and F-4949 across different tactical tasks. An "*" indicates statistical significance at the $\alpha < 0.01$ level. PNVG I appears to have been most beneficial during threat detection, formation and tactics, offensive maneuvering, defensive maneuvering, and for survivability.

3.1.6 Overall comparison

Pilots were asked to rate the suitability of the PNVG I FOV compared to the F-4949 FOV. The results indicate that the pilots feel that the PNVG I FOV is very effective (mean rating = 4.66, $p < 0.00001$). When asked to make an overall preference comparison of the PNVG I vs. F-4949, 15 of the 16 responses indicate a preference for PNVG I (93.33%).

3.1.7 Representative PNVG I positive comments

"I did not experience any eye strain or headaches." "A must have." "A-10's need these!" "Closer to face, better FOV rather obvious!" "Outer channels were focused much better (20/25)." "Had better SA awareness of my surroundings." "Easier to fly at lower altitudes." "Could spend more time scanning for bandits and watching where my flight path is." "Less forward CG when looking through."

3.1.8 Representative PNVG I negative comments

"Lack of adjustability." "The battery change out is unsat." "I lost a battery down inside the helmet cover when trying to change out!" "In order to see the HMD display, I had to have the right channels way over to the left (toward the center of my face)." "This caused me to lose the outer part of the right outer channel." "Need to adjust focus rings." "They are too hard to work with gloves on." "Need more play in the areas that we normally focus (infinity)." "The 'bridge' that holds the goggle is worn and breaks loose at 6 g's or greater." "Requires me to reach up and snap it back into place." "More difficult to see inside the cockpit, especially under g's." "Very difficult to set up the radar while in turn." "Not as crisp." "Flimsy trapeze, tilt sags under G." "Adjustments not user friendly." "Had to lower seat 2 inches to get proper eye height relative to HUD." "Delicate innards exposed when removed from helmet for stowing."

3.2 C-5 / C-130 PNVG II evaluation

The following paragraphs present the questionnaire data collected to date. The information represents averages derived across all survey 21 respondents. It is indicated where feedback is specific to an aircraft type (C-5 or C-130). Statistical analyses (two-tailed t tests) were performed to determine if the recorded ratings differed reliably from a rating of 3 (a rating of 3 indicates that PNVG II and F-4949 performance was the same).

3.2.1 Descriptive information

Average duration of PNVG II experience during the C-130 and C-5 flights were 1.1 hours. Illumination conditions were described as low for all (25% moon or less) of the flights. Observed weather was described as clear for all of the flights.

3.2.2 Fit, function, and human factors ratings

Pilots found the PNVG II to be significantly less fatiguing compared to F-4949 (mean rating = 3.42, $p < 0.05$). The ability to adjust PNVG II was rated as significantly worse compared to F-4949 (mean rating = 2.10, $p = 0.001$). None of the other fit, function, and human factors ratings for PNVG II differed significantly from the same as F-4949. These questions included the ability to adjust the PNVG II with gloved hand: up/down, in/out, or diopter setting. Ease to don and doff PNVG II was rated as similar to F-4949. Also the same were overall comfort, comfort in the operational and stowed position, neck strain, helmet fit, compatibility with eyewear, stability under G, weight, balance, hot spots, integration with life support equipment, and the ability to detect the "battery weak" indicator.

3.2.3 Cockpit/cockpit lighting compatibility

For the questions asked, PNVG II and F-4949 were not rated as differing. The questions addressed the view below the PNVG II (to see controls and displays), the use of lapboards/notes/flight cards, and compatibility with cockpit lighting.

3.2.4 Image quality

Image quality of PNVG II was rated as greater than that of F-4949 (mean rating = 3.55, $p < 0.05$). Field of view through PNVG II was rated as significantly greater than F-4949 (mean rating = 4.5, $p < 0.0001$). The following ratings also indicated a preference for PNVG II: Response to cultural lighting (mean rating = 3.79, $p = 0.001$), lack of blooming (mean rating = 3.65, $p = 0.011$), lack of fogging (mean rating = 3.56, $p = 0.007$), acceptability of image brightness (mean rating = 3.62, $p = 0.004$), acceptability of noise level (mean rating = 3.68, $p = 0.002$), performance at low (moon < 25%) light levels (mean rating = 3.65, $p < 0.05$), and performance when viewing cultural lighting (mean rating = 3.63, $p = 0.01$). For the following, PNVG II performance was rated as no different than F-4949: Freedom from visual obstructions, near focus visual accommodation, far focus accommodation, and performance at high (moon > 25%) light levels.

3.2.5 Operational employment

The participants reported that overall, SA was enhanced by the use of PNVG II compared to F-4949 (mean rating = 4.1, $p < 0.0001$). Figure 9 shows the mean ratings comparing PNVG II and F-4949 across different operational tasks. An "*" indicates statistical significance at alpha at least less than 0.01 level. PNVG II appears to have been most beneficial during threat detection, formation holding, and area clearing.

3.2.6 Overall comparison

Pilots were asked to rate the overall acceptability and desirability of the PNVG II system compared to the F-4949 NVG. The results indicate a strong preference for PNVG II (mean rating = 3.95, $p < 0.0001$). Similarly, pilots were asked to rate the overall mission and task performance benefit of the PNVG II compared to the F-4949. Again, the PNVG II system was rated as most beneficial (mean rating = 4.0, $p < 0.0001$).

3.2.7 Representative PNVG II positive comments

"The panoramic vision greatly increased mission capabilities by decreasing the amount of head movement required for the pilot to scan. This in turn reduced the amount of work." "Overall very impressive--much less time scanning, much more time spent looking--situation awareness dramatically increased." "PNVGs definitely enhance mission effectiveness. The peripheral vision alone is a dramatic capability enhancement. The battery pack incorporated into the PNVG is also nice." "Panoramic vision greatly increases SA and clearing ability."

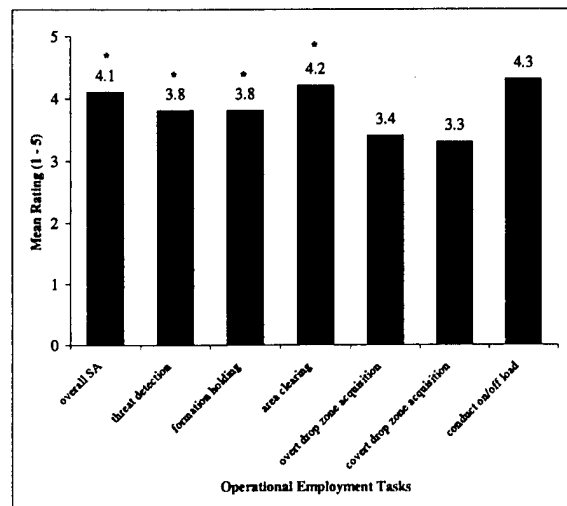


Figure 9. PNVG II ratings as a function of operational employment task

3.2.8 Representative PNVG II negative comments

"PNVGs need: wider range of focus. Outer tubes need focus ability, more field of view up and down would be nice too."
"PNVG objective lens seem harder to adjust than 4949, the knobs are hard to turn. Very heavy when stowed. PNVG needs more near focusing for close up work (1 - 2 foot range)." *"Suggest better focus on inner tubes and focus capability on outer tubes."* *"Also because you need the NVGs close to your eyes to eliminate the "lines" it makes viewing cockpit instruments difficult under the PNVGs compared to the 4949s."*

4. OBJECTIVES FOR NEXT PHASE OF PNVG

The PNVG program is scheduled to complete source selection for the next phase in April 2000 to optimize the wide FOV concept and correct deficiencies identified in the current round of flight test. In addition, the Army has joined the team to complement the Air Force's effort to develop the next-generation PNVG. The preferred approach would be to develop one design to satisfy the mission requirements versus the current two-configuration approach. The next few paragraphs will summarize some of the key objectives of the next PNVG effort.⁴

4.1 Wide Field-of-View

The current PNVGs were developed under the Small Business Innovative Research (SBIR) program that program did not perform trade studies to determine the optimal FOV. This next phase will review the literature and conduct trade studies to develop an optimal FOV design. The system will be required to have an instantaneous horizontal FOV ≥ 80 degrees with a binocular overlap ≥ 36 degrees, and a instantaneous vertical FOV ≥ 36 degrees.

4.2 Laser Eye Protection (LEP)

Laser threats to military aircrew are real with reports from foreign sources and the presence lasers are expected to grow on the battlefield. These incidents have raised concern for the health of aircrew eyes, for mission effectiveness, and for flight safety. This new contract will incorporate LEP technologies for protection of the human and the goggles. The designs will have to accommodate the latest LEP visor, spectacles, and light interference filters. Laser hardening of the image intensifier tube should be incorporated.

4.3 Fit/Comfort

The fit and comfort to the operator while wearing the PNVG will be examined. The PNVG will need to accommodate a diverse population of operators that will be flying in different mission environments with varying mission durations. Some of different items that will be considered in the design are weight and center of gravity (down and stowed positions), ease of mechanical adjustments, stability of the NVG/helmet to accommodate G loads and rapid head movements, cockpit compatibility, and adequate eye relief.

4.4 Image Quality

The device needs to have image quality equal to or better than NVGs delivered under the Army Omni V contract. Attributes for satisfying the requirement that need to be considered are the expected visual acuity (resolution) through the device for quarter moon and starlight light levels, signal-to-noise ratio, image tube halo, optical distortion, optical image alignment, system modulation transfer function (MTF - on axis and at edges of the field), eyepiece focus, eye position tolerance and effects on optical MTF, objective lens focus, and maximum image luminance. If partial overlap of visual fields is used to produce the wide FOV, the image discontinuity tolerances at the overlap should be addressed including image luminance uniformity, image magnification, rotation, distortion, and horizontal and vertical off-set.

4.5 Integrated Symbolology/Imagery Display

The electronic interface needs to be extended from the current symbology overlay technique to include imagery insertion by using a light-valve or similar technology to block the NVG image during imagery display and single-channel miniature camera record. The inclusion of a full-color version of the miniature flat panel image source will also be considered. The

PNVG will provide the capability to remove/replace either or both the flat panel image source and the miniature camera in the field. The PNVG will remain mission capable as a separate functioning system with either or both functions removed. The instantaneous FOV provided for the imagery insertion should be compatible with current navigation-FLIR sensors. Compatibility with Joint Helmet Mounted Cueing System (JHMCS), VCATS, Air Warrior, and Land Warrior will be considered. Finally, the allocation of electronics between the PNVG device and its associated helmet vehicle interface module will be addressed with respect to its impact on operational use of the system.

4.6 Field Support

The device should be designed in order to minimize the need for any additional logistic support equipment. This means the design will allow field-level performance testing utilizing the ANV-126 Hoffman tester with little or no disassembly of the PNVG device or major modification to the tester. Adjustment knobs should be useable while wearing flight and chemical/biological gloves.

4.7 Ejection/Crash/Ground Egress Safety

Flight safety and environmental use have to be factored into the design. The following areas need to be examined in the performing of safety testing: Mertz criteria, Knox Box, USAARL curve, inertial properties testing, vertical impact testing, helmet impact testing, visor ballistics testing, helmet penetration testing, rapid and explosive decompression testing, ejection windblast testing, quick disconnect functionality, hanging harness testing, cockpit compatibility testing, electromagnetic compatibility testing, emergency ground egress testing, and electrical shock analysis.

4.8 Compatible with Existing Systems

The new system will need to be interoperable with existing systems. The items that need to be addressed are the helmet, oxygen mask, nuclear/biological/chemical masks, Aviator Night Vision Imaging System mount, survival vest, anti exposure suit, torso harness, aircrew spectacles, back style parachutes, and personal clothing.

4.9 - Ilities

The PNVG design must optimize reliability, maintainability, affordability, producibility and supportability. System and System sub-components should be capable of mass production while consistently maintaining pre-established standards. A design that requires only minimal maintenance is desirable. Pre or post-flight checkout and maintenance procedures should be kept to a minimum. Major components should be interchangeable if a two-configuration approach is adopted.

5. CONCLUSION

The PNVG feedback has been very positive and indicates that a 100-degree FOV significantly improves pilot performance across different operational tasks compared to the 40-degree F-4949. The significant increase in intensified FOV not only enhances mission effectiveness, but also gets us even closer to our goal of being able to do daytime-like tactics at night. This pilot feedback is not complete though. Additional flights on F-15s as well as other aircraft are planned and will be used for further evaluation. Suggested areas for PNVG improvements will be addressed in an upcoming follow-on advanced technology demonstration program.

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